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ALTERNATIVE PROCEDURE FOR DETERMINING THE SHRINKAGE LIMIT OF SOIL

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16. ABSTRACT

An alternative procedure for determining the shrinkage limit of soil has been developed. This procedure does not use toxic mercury for volume measurements and, therefore, provides a safe and simple way to determine shrinkage factors. The results obtained using the alternative procedure are as precise and repeatable as those obtained using the standard procedure.

17. KEY WORDS AND DOCUMENT ANALYSIS

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by

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June 1986

Geotechnical Branch
Division of Research and Laboratory Services
Engineering and Research Center
Denver, Colorado

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

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INTRODUCTION

This report presents an alternative test procedure for obtaining the shrinkage limit of a soil. This procedure includes a method for calibrating the shrinkage dish and for calculating the shrinkage ratio, and it eliminates the use of mercury in determining the shrinkage limit.

The procedure now used by the Bureau of Reclamation to identify shrinkage factors of soils is outlined in the *Earth Manual* [1]*, designation E-7, part C, "Shrinkage Factors of Soils," pages 446 to 448, which is adapted from ASTM D 427-61 [2]. Using this current procedure, the volume of the ovendried soil pat is determined by immersing it in a reservoir of mercury. The volume of the pat is equal to the volume of displaced mercury. The disadvantage of this procedure lies in the special safety precautions required when handling mercury.

Mercury is one of the oldest known industrial poisons. It is highly toxic to body tissues and can be readily absorbed into the body by way of the respiratory and digestive systems as well as directly through the skin [3, 4, 5]. Because of the numerous hazards associated with the use of mercury, it is advantageous to eliminate its use in the shrinkage limit test.

An alternative method of determining the shrinkage limit of soil has been developed. This method eliminates the use of mercury from the test procedure: The volume of the dry soil pat is determined by submersing it in water after coating it with paraffin or microcrystalline wax. The complete procedure is presented in appendix A.

SUMMARY AND CONCLUSIONS

The study investigating the alternative method for determining the shrinkage limit of soils concentrated on comparing the results of tests performed using mercury with those performed using water for soil pat volume determinations. Duplicate specimens were tested to determine the precision and repeatability of shrinkage limit values obtained using the *Earth Manual* (mercury) procedure (designation E-7, part C) and the alternative (wax) procedure.

Data indicate that results obtained from either the alternative (wax) method or the standard (mercury) method are reasonably precise and repeatable. While the alternative (wax) procedure may produce shrinkage limit values slightly higher than those obtained using the standard (mercury) procedure, it is considered a valid test method. However, when the shrinkage limit of a soil is critical or when unusual soil types are encountered, the standard (mercury) method is recommended because of the historical data base available.

The principal advantage of the wax method is the elimination of mercury from repetitive laboratory tests, for health and safety reasons. Instead of immersing a bare soil pat in mercury, paraffin-coated soil specimens are immersed in water to determine the volume of the ovendried pat. Table 1 shows the relation of shrinkage limit and probable volume change.

SHRINKAGE LIMIT

The shrinkage limit of a soil is defined as "the maximum water content at which a reduction in water content will not cause a decrease in volume of the soil mass." The shrinkage ratio is defined as "the ratio of a given volume change, expressed as a percentage of the dry volume, to the corresponding change in water content above the shrinkage limit, expressed as a percentage of the dry volume, to the corresponding change in water content above the shrinkage limit, expressed as a percentage of the weight of the ovendried soil"[1].

The shrinkage limit is usually determined for soils believed susceptible to a large change in volume with a change in moisture content. It indicates whether a soil may be susceptible to large volume change. Soils with a shrinkage limit less than 11 are usually tested in a one-dimensional consolidation device to assess their potential for swelling or shrinkage. And particular attention is given to soils with shrinkage limits of 9 or less. Table 1 shows soil index properties and volume changes.

Table 1. – Relations of soil index properties and probable volume changes for highly plastic soils [1].

Data from index tests[1]			Estimation of probable expansion,[2] % total volume change (dry to saturated condition)	
Colloid content (% minus 0.001 mm)	Plasticity index	Shrinkage limit, %		Degree of expansion
>28	>35	<11	>30	Very high
20–31	25–41	7–12	20–30	High
13–23	15–28	10–16	10–20	Medium
<15	<18	>15	<10	Low

[1] All three index tests should be considered in estimating expansive properties.

[2] Based on a vertical loading of 1.0 lbf/in^2 as for concrete canal lining. For higher loadings the amount of expansion is reduced, depending on the load and on the clay characteristics.

* Numbers in brackets refer to entries in the bibliography.

REPEATABILITY OF THE STANDARD (MERCURY) METHOD

One ovendried shrinkage limit soil pat was made from sample No. PS-5. This soil pat was used 20 times to determine the shrinkage limit. The shrinkage limit ranged from 7.8 to 9.6 percent with a mean of 8.6 percent (table 2). The repeatability of the mercury method for determining the shrinkage limit of a single specimen is shown on figure 1.

Twenty duplicate ovendried shrinkage limit soil pats were prepared from soil sample No. PS-5. The shrinkage limit was determined by the standard (mercury) method on each of the 20 specimens (table 3). The shrinkage limit values ranged from 7.2 to 12 percent, with a mean of 9.2 percent. The frequency of occurrence plot (figure 2) shows the shrinkage limit frequency distribution. Note the biomodal (dual peak) distribution.

Four shrinkage limit soilpats were prepared from each of thirty soil samples (120 specimens) for shrinkage limit determination. Two soil pats from each soil sample were tested using each method; the data are presented in table 4. Data from specimens tested by the mercury method are plotted on figure 3.

The data correlate fairly well; however, the significant scatter indicates the difficulty of preparing four identical, duplicate ovendried soil pats, although they come from the same soil. In the worst case the shrinkage limit varied by 12 percentage points (sample No. 59N-267) between the first and second specimens tested by the mercury method.

Table 2. – Shrinkage limit repeatability (sample No. PS-5, one specimen prepared for each method).

Trial No.	Mercury method specimen 1, %	Wax method specimen 2, %
1	9.1	7.8
2	9.6	7.8
3	8.6	7.8
4	8.5	7.8
5	8.4	7.8
6	8.3	7.8
7	9.2	7.8
8	8.0	7.8
9	8.8	7.8
10	7.8	7.8
11	8.7	7.8
12	8.7	7.8
13	8.7	7.8
14	8.7	7.8
15	8.7	7.8
16	8.6	7.8
17	8.6	7.8
18	8.5	7.8
19	8.5	7.8
20	8.4	7.8
Mean	8.6	7.8
Range	1.8	0.0

Next, 87 ovendried soil pats were prepared from 25 different soils. Shrinkage limits were determined by the mercury method and by two wax methods on each soil pat, for direct comparison of the two methods. Data are presented in table 5 and plotted on figures 4 and 5.

Data shown on figures 1 and 2 indicate considerable variation in repeatability and precision using the standard mercury method for determining the shrinkage limit of soils.

REPEATABILITY OF THE ALTERNATIVE (WAX) METHOD

One duplicate of the shrinkage limit soil pat used in the mercury method was made from sample No. PS-5. Because the soil pat could be coated with wax only once, it was coated and weighed 20 times. The shrinkage limit was determined to be 7.8 on all trials, indicating that water absorption in the thread did not affect the test results (table 2). The precision of the wax method for determining shrinkage limit (repeatability of measurements using a single specimen) is shown on figure 6.

Twenty duplicate ovendried shrinkage limit soil pats were prepared from sample No. PS-5. The shrinkage limit was determined on each of the 20 wax coated soil pat by the weight (weight in air and weight in water). The shrinkage limit values ranged from 5.1 to 10 percent with mean of 6.9 percent. The data are presented (table 3). The frequency of occurrence plot on figure 7 shows the shrinkage limit distribution.

Four shrinkage limit soil pats were prepared from each of 30 soil samples (120 specimens) for shrinkage limit determination. Two soil pats from each sample were tested using the mercury method, the other two pats using the wax method. The data (presented in table 4 and plotted on fig. 8) indicate fairly good repeatability, but again show the difficulty of preparing identical, ovendried soil pats, although they are taken from the same soil. The worst case discovered using the wax method had a difference of 4 percentage points (both 59N-259 and 270) between the first and second specimens.

Two methods of determining the volume of ovendried wax coated soil pats were studied using the 87 pats prepared from 25 different soils. The weight method and the volume displacement (siphon) method were investigated. Data comparing these two methods are shown in table 5 and on figure 9.

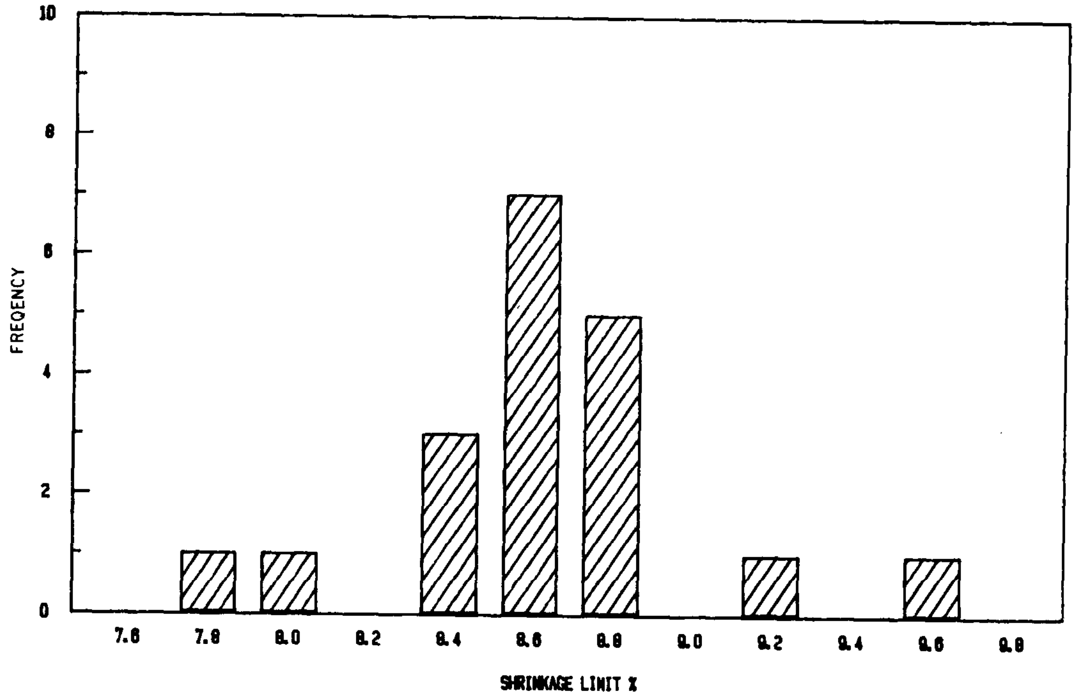

Figure 1. – Frequencies of shrinkage limit values determined 20 times by the mercury method, for one specimen.

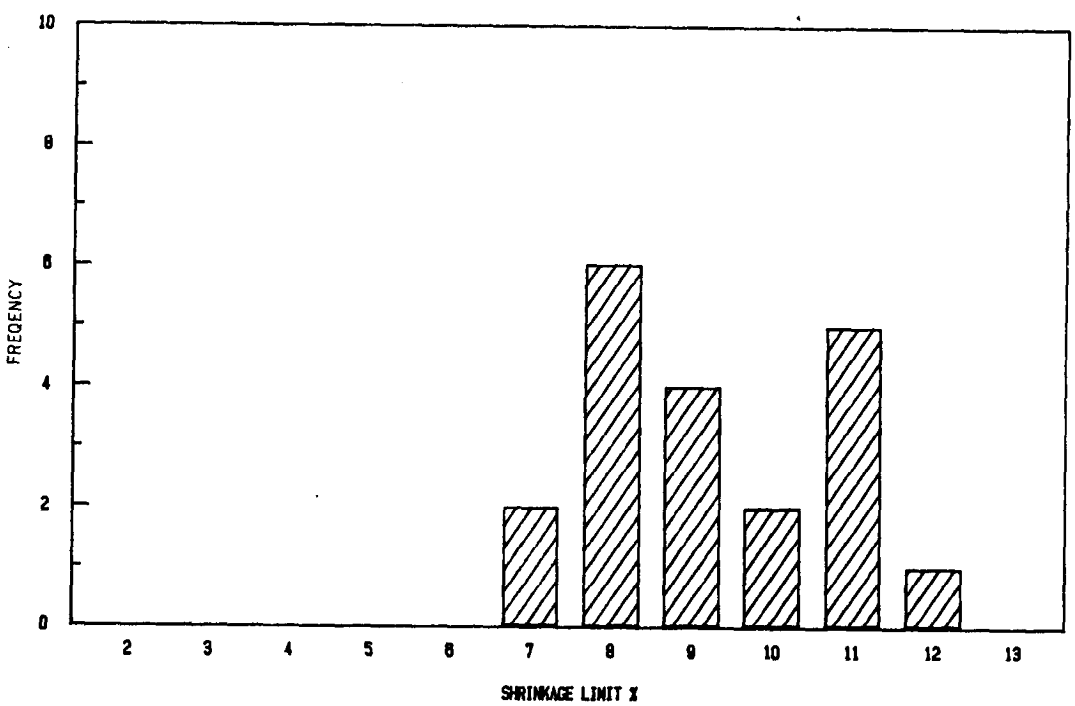

Figure 2. – Frequencies of shrinkage limit values determined by the mercury method, for 20 specimens of one sample.

Table 3. – Shrinkage limit soil variability (sample No. PS-5, twenty specimens prepared for each method).

Specimen No.	Mercury method, %	Specimen No.	Wax method, %
1	8.2	21	5.7
2	10.0	22	6.1
3	7.6	23	6.2
4	9.2	24	7.1
5	7.9	25	7.8
6	8.3	26	7.3
7	8.6	27	7.8
8	12.0	28	6.9
9	11.0	29	5.4
10	8.2	30	8.6
11	11.0	31	5.6
12	10.0	32	7.3
13	11.0	33	7.5
14	8.8	34	6.1
15	7.2	35	6.8
16	7.6	36	10.0
17	7.2	37	5.1
18	11.0	38	6.3
19	11.0	39	6.9
20	8.8	40	7.3
Mean	9.2		6.9
Range	4.8		4.9

Table 4. – Duplicate soil specimen shrinkage limit comparison (four specimens prepared from each soil sample).

Sample No.	Mercury			Wax		
	1st test, %	2d test, %	Mean	1st test, %	2d test, %	Mean
59N-258	18	17	17.5	15	14	14.5
259	10	12	11.0	11	7	9.0
267	22	34	28.0	21	20	20.5
270	26	32	29.0	22	18	20.0
271	25	20	22.5	17	14	15.5
276	26	28	27.0	22	23	22.5
277	28	35	31.5	25	28	26.5
282	14	21	17.5	13	12	12.5
285	22	11	16.5	15	14	14.5
288	14	11	12.5	12	14	13.0
291	18	16	17.0	11	12	11.5
55J-364	8.1	5.4	6.8	8.1	7.8	7.9
365	12	12	12.0	10	11	10.5
366	9.5	10	9.8	12	12	12.0
367	10	10	10.0	12	10	11.0
368	11	12	11.0	11	12	11.5
370	14	12	13.0	12	12	12.0
371	12	8.9	10.4	12	12	12.0
59B-23	9.6	8.0	8.8	9.6	9.9	9.8
46	12	8.1	10.0	8.8	10	9.4
50	9.0	8.1	8.6	8.9	8.8	8.8
55T-13	9.0	8.1	8.6	8.9	8.8	8.8
14	13	10	11.5	14	13	13.5
21	19	21	20.0	18	20	19.0
36	9.3	8.3	8.8	9.5	10	9.8
61	22	22	22.0	21	21	21.0
81	23	23	23.0	23	25	24.0
90	7.5	7.4	7.4	7.5	7.8	7.6
59J-361	8.5	7.6	8.0	9.3	7.6	8.4
363	8.2	9.1	8.6	8.4	10	9.2
Mean	15.0	14.9	14.9	13.6	13.5	13.5

Table 5. – Comparison of shrinkage limit values for 87 soil pats, determined by three different methods.

Sample No.	Specimen No.	Mercury method, %	Wax method	
			Weight, %	Siphon, %
55T-13	1	43	43	46
	2	42	42	44
	3	40	38	39
	4	41	40	43
55T-14	1	13	14	17
	2	11	12	13
55T-21	1	19	18	18
	2	21	20	22
55T-23	1	7.5	7.2	7.2
55T-36	1	7.5	9.5	9.6
	2	9.3	10	10
55T-61	1	19	21	21
	2	18	19	19
	3	22	21	23
	4	22	21	22
55T-81	1	23	23	25
	2	25	27	28
	3	25	23	24
	4	23	22	23
55T-90	1	5.5	5.5	6.1
	2	7.5	7.5	7.5
	3	7.4	7.8	7.7
	4	6.8	9.1	10
55J-361	1	8.5	9.3	9.4
	2	7.6	7.6	7.8
55J-362	1	9.4	10	10
	2	11	10	9.8
55J-363	1	9.5	10	10
	2	9.1	11	11
55J-364	1	6.3	8.6	8.8
	2	7.9	7.5	7.6
	3	8.1	8.0	7.8
	4	5.4	5.1	5.2
55J-365	1	12	13	14
	2	10	12	13
	3	11	12	11
	4	10	10	11
55J-366	1	10	11	11
	2	10	12	12
	3	9.9	12	11
	4	9.5	12	13
55J-367	1	10	12	13
	2	10	10	11
55J-368	1	11	11	12
	2	12	12	13
55J-369	1	11	12	12
	2	11	10	11
55J-370	1	14	14	14
	2	10	11	12
	3	5.9	9.9	10
	4	10	12	12
55J-371	1	12	12	12
	2	14	15	14
	3	8.8	11	12
	4	8.3	9.9	10
59B-23	1	9.6	9.7	9.8
	2	8.0	9.9	10
	3	11	10	11
	4	11	11	11
59B-46	1	12.3	11	11
	2	8.1	8.6	8.8
	3	6.4	6.7	6.6
	4	6.1	6.7	6.6

Table 5. – Comparison of shrinkage limit values for 87 soil pats, determined by three different methods. – Continued

Sample No.	Specimen No.	Mercury method, %	Wax method Weight, %	Wax method Siphon, %
59B-50	1	9.0	8.9	9.0
	2	8.1	8.8	9.0
Georgia	1	26	23	23
Kaolin	2	22	22	23
	3	27	30	31
	4	28	26	26
	5	25	21	20
	6	26	22	22
24G-1	1	17	14	17
	2	16	12	12
22L-1	1	9.3	8.2	8.4
	2	9.8	9.8	9.8
	3	10	9.5	9.6
	4	9.5	10	10
	5	8.8	8.8	8.8
	6	6.5	8.5	8.6
	7	9.4	8.2	8.2
	8	8.2	6.7	6.8
	9	9.2	11	11
	10	7.2	7.9	8.0
	11	6.6	9.3	9.4
	12	9.1	8.3	8.4
	13	9.5	7.9	8.0
	15	8.6	10	10
Mean		13.4	13.7	14.1

The mean of the shrinkage limits determined by the volume displacement (siphon) method is slightly higher than that determined by the weight method, 14.1 percent compared with 13.7 percent (table 5); both are slightly higher than the average shrinkage limit determined by the mercury method, 13.4 percent. The siphon method produced slightly higher shrinkage limit values than the weight method. Fifty-three specimens had shrinkage limits with ±0.2 percentage points, 22 specimens with ±0.6 to 1.0 percentage points, 4 specimens with +2 percentage points, four specimens with +3 percentage points, and four specimens with −1 percentage point (where plus means the siphon value was larger than the weight value). The data indicate that either method is acceptable, although the weight method is preferred because it produces values closer to those obtained using the mercury method. Both methods are described in appendix A.

Data shown on figures 5, 6, and 7, indicate good repeatability and precision of the alternative (wax) method for determining soil shrinkage limits.

COMPARISON OF METHODS

Plots of shrinkage limit determined by the mercury method vs. the alternative (wax) method (by siphon and by weight) are shown on figures 4 and 5, respectively. The shrinkage limit was determined on each of 87 soil pats from 25 different soils using each of the three methods (table 5). As can be seen from the plots, when the shrinkage limit is determined on the same soil pat by either the mercury or the alternative (wax) methods, the results show very good correlation, although the values determined by the wax by weight method are slightly higher than those determined by the mercury method, and values determined by the siphon wax method are higher still. Therefore, because it produces values closer to those obtained by the mercury method, the wax method by weight should be used. Although the alternative (wax) method is valid, in cases where the shrinkage limit of a soil is critical, or when unusual soil types are encountered, the standard (mercury) method is recommended because of the historical data base available.

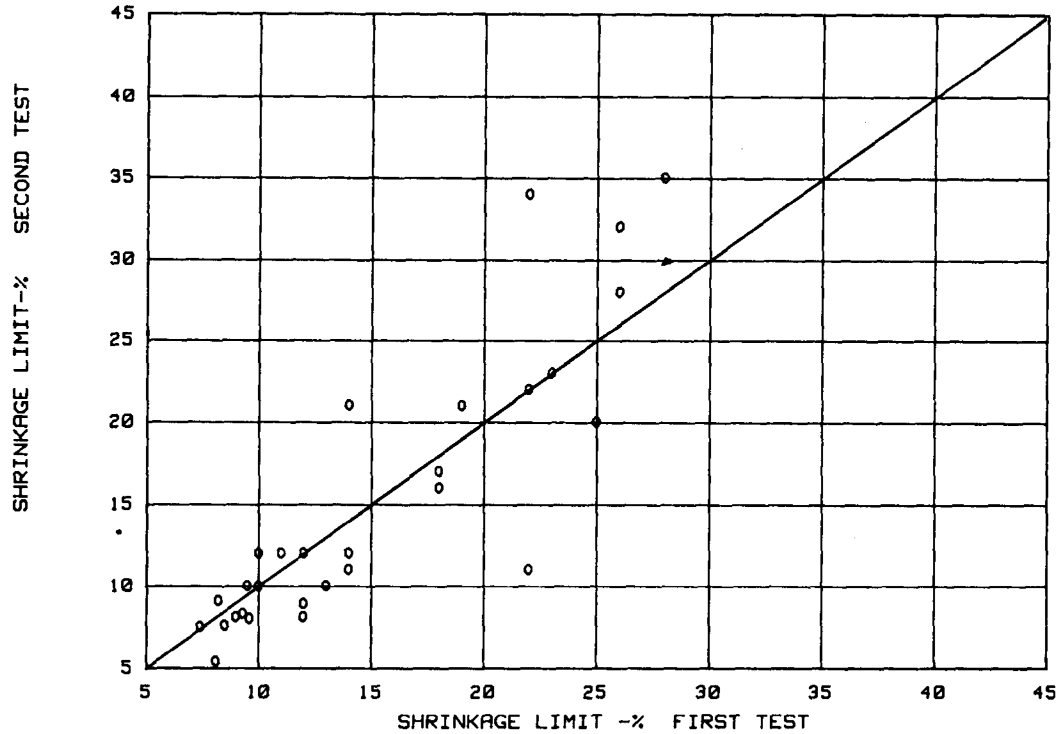

Figure 3. – Precision of shrinkage limit values determined by the mercury method, for 60 specimens from 30 samples.

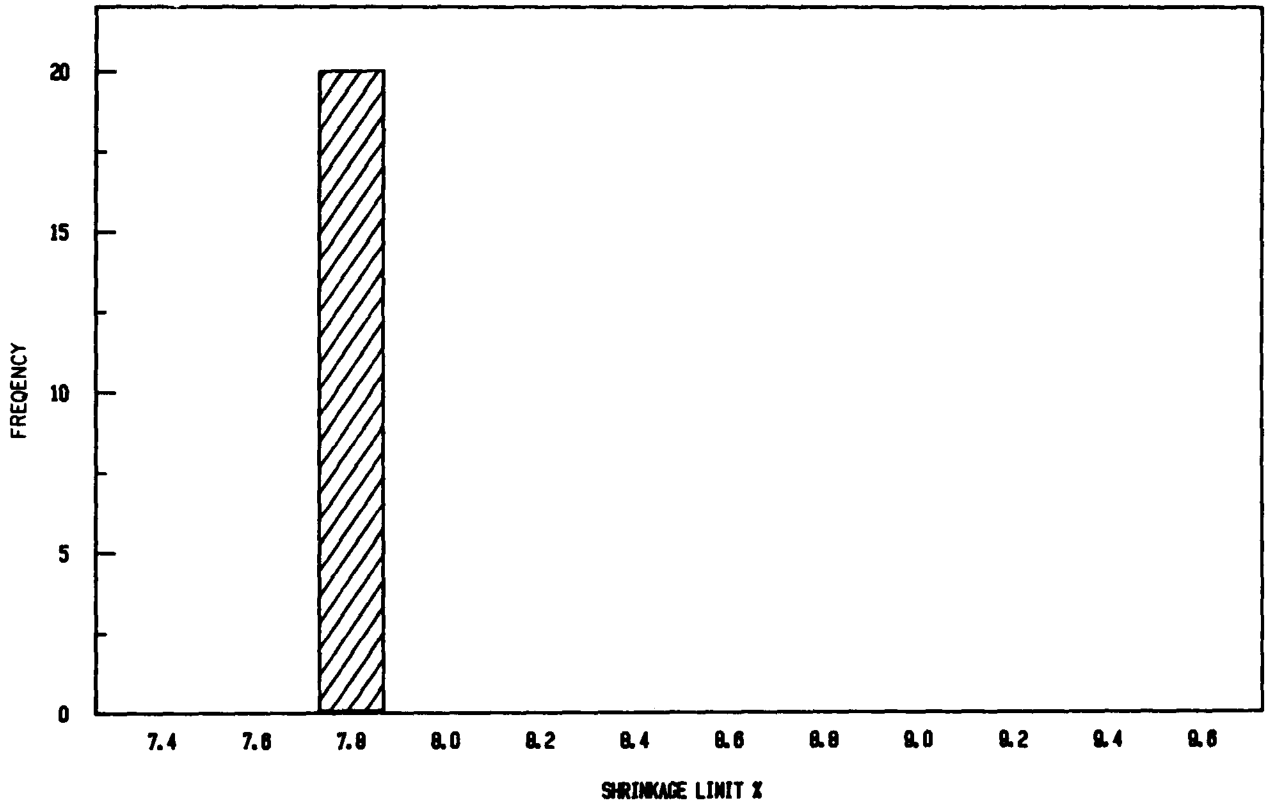

Figure 4. – Comparison of shrinkage limit values determined by the mercury method and the wax (siphon) method.

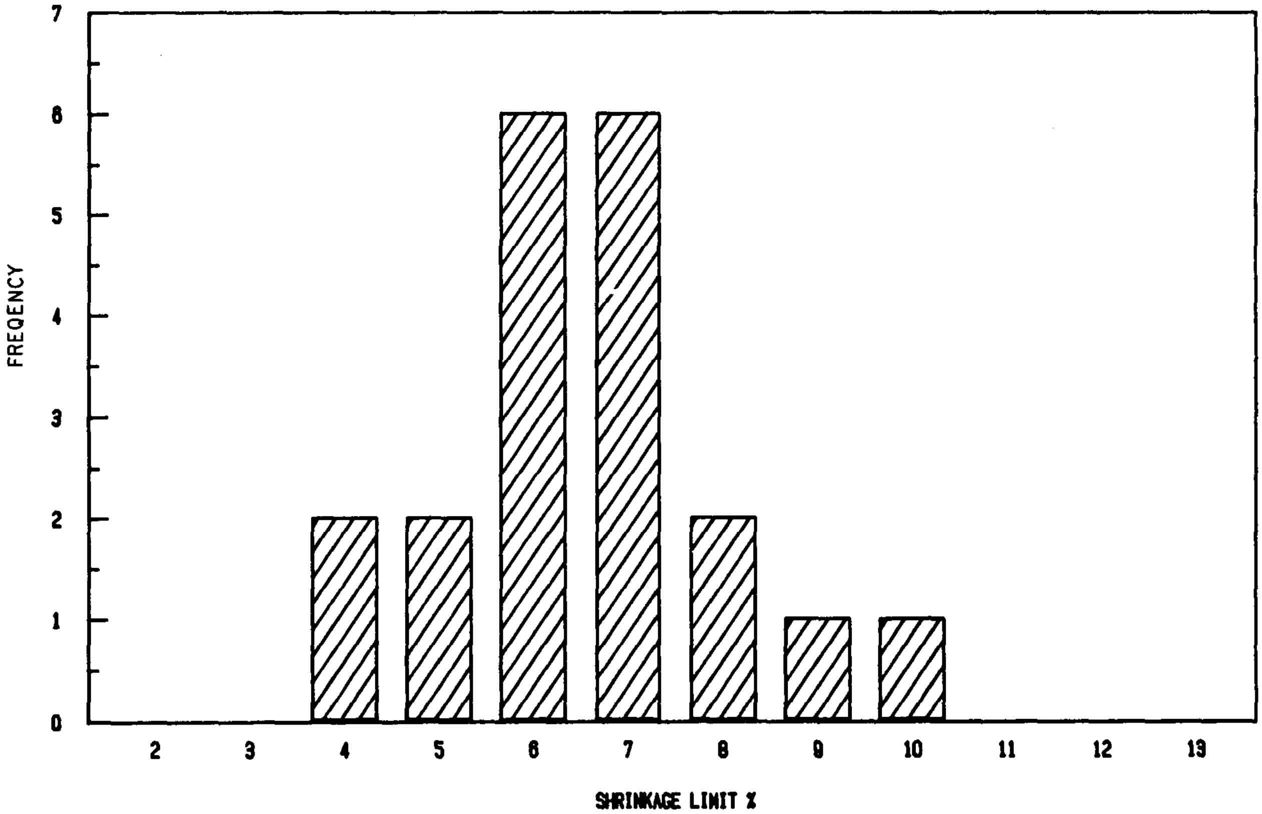

Figure 5. – Comparison of shrinkage limit values determined by the mercury method and the wax (weight) method.

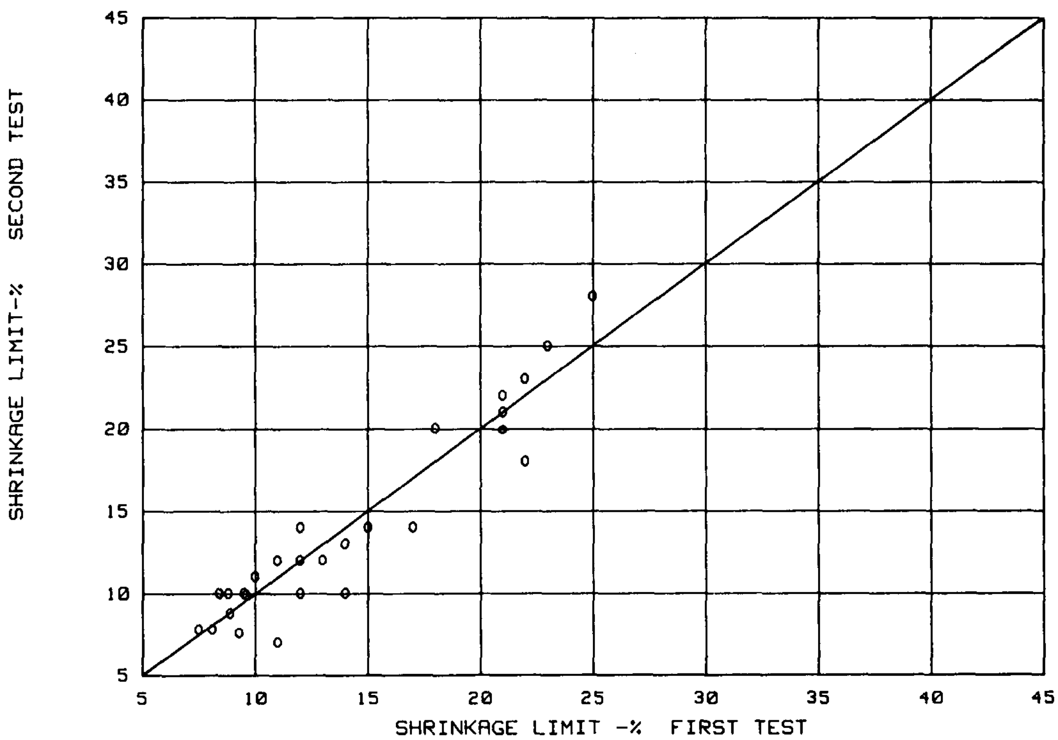

Figure 6. – Frequencies of shrinkage limit values determined 20 times by the wax method, for one specimen.

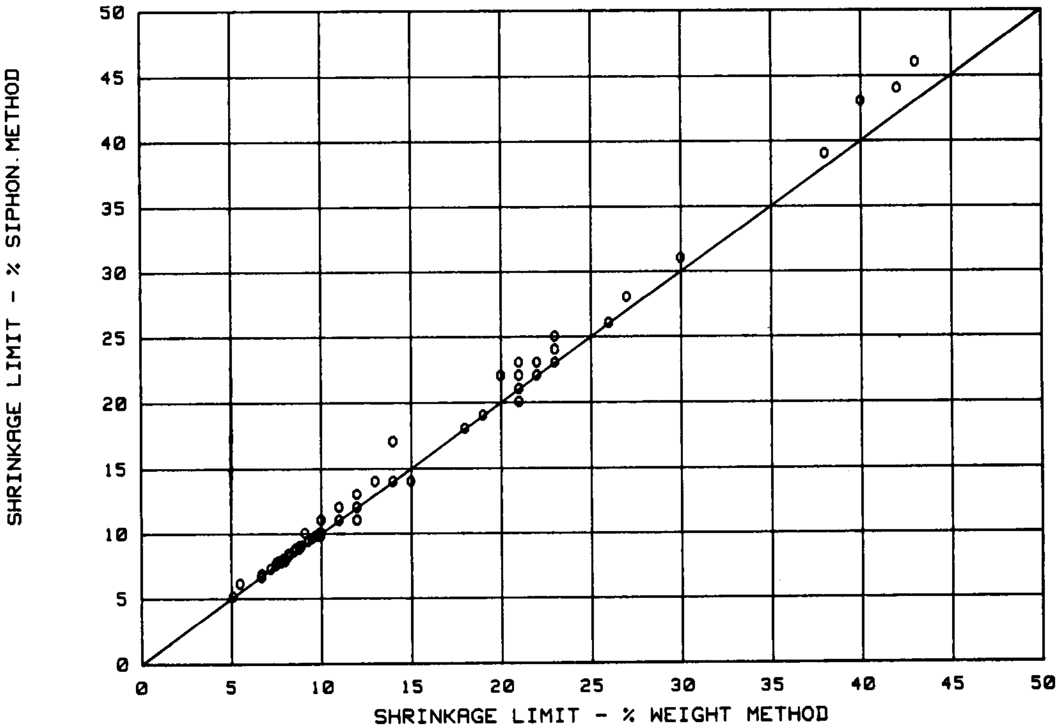

Figure 7. – Frequencies of shrinkage limit values determined by the wax method, for 20 specimens of one sample.

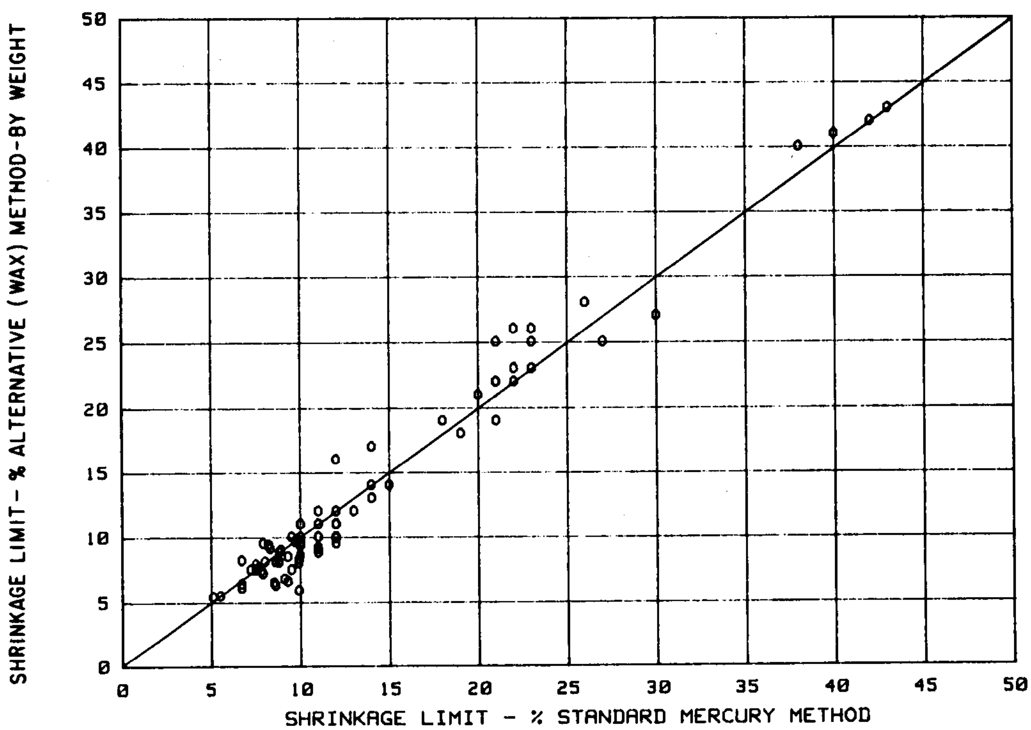

Figure 8. – Precision of shrinkage limit values determined by the wax method, for 60 specimens from 30 samples.

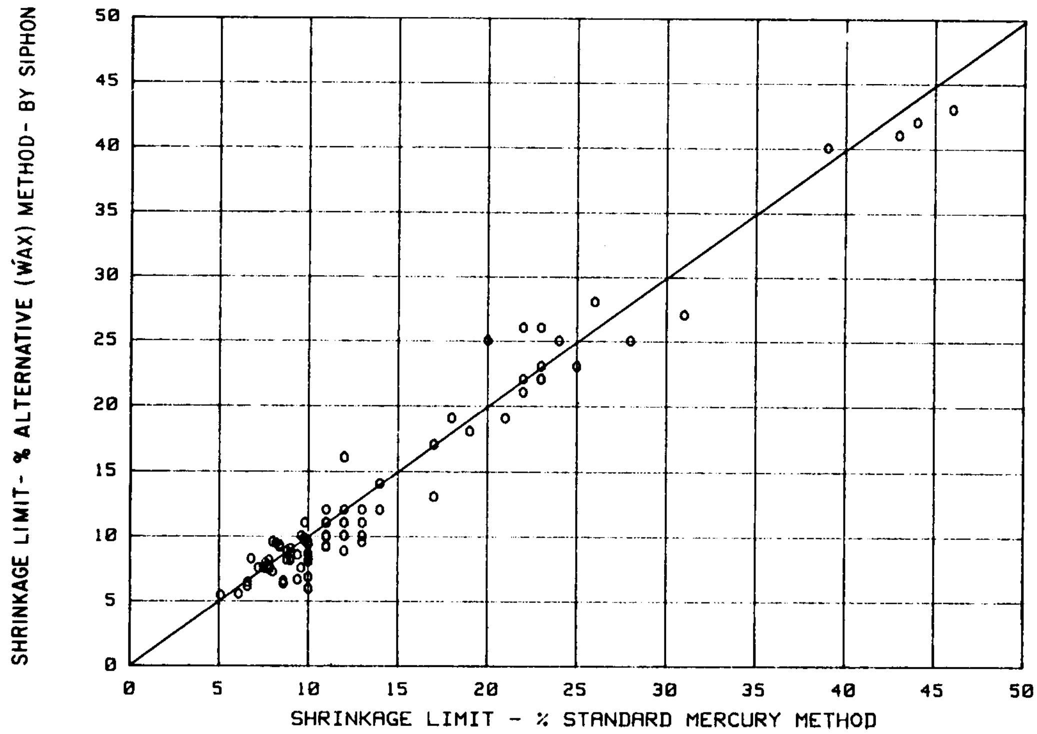

Figure 9. – Comparison of shrinkage limit values determined by the weight method and the siphon method, for 87 pats.

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Holtham, B. F., Memorandum to Chief, Geotechnical Branch, Subject: "Evaluation of Employee Suggestion Submitted by Thomas E. England, Materials Engineering Technician, Construction Division, Huron, South Dakota, Concerning an Alternate Procedure for Determining the Shrinkage Factors of Soils," Bureau of Reclamation, Denver, CO, October 11, 1977.

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APPENDIX A

PROCEDURE FOR DETERMINING SHRINKAGE LIMIT AND SHRINKAGE RATIOS OF SOILS

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 5365-84

PROCEDURE FOR

DETERMINING SHRINKAGE LIMIT AND SHRINKAGE RATIO OF SOILS

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Branch, code D-1540, Division of Research and Laboratory Services, E&R Center, Denver, Colorado. The procedure is issued under the fixed designation USBR 5365. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for determining the shrinkage limit and shrinkage ratio of a cohesive soil.

1.2 The data obtained using this procedure may be used to calculate shrinkage limit, shrinkage ratio, volumetric shrinkage, linear shrinkage, and approximate specific gravity.

1.3 Two alternative procedures are provided.

1.3.1 In method A, the mass in air minus the mass in water is used to determine the volume of the dried soil pat, and is referred to as the wax method.

1.3.2 In method B, the volume of displaced mercury is used to determine the volume of the dried soil pat, and is referred to as the mercury method.

2. Auxiliary Tests

2.1 A representative soil sample must be obtained in accordance with USBR 5205 prior to performing this procedure. The moisture content must be determined in accordance with USBR 5300 as part of performing this procedure.

3. Applicable Documents

3.1 *USBR Procedures*:

USBR 1012 Calibrating Balances and Scales
USBR 1020 Calibrating Ovens
USBR 1025 Calibrating Sieves and Screens
USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics
USBR 5000 Determining Unified Soil Classification (Laboratory Method)
USBR 5005 Determining Unified Soil Classification (Visual Method)
USBR 5205 Preparing Soil Samples by Splitting or Quartering
USBR 5300 Determining Moisture Content of Soil and Rock by the Oven Method
USBR 5350 Determining Liquid Limit of Soils by the One-Point Method
USBR 5355 Determining Liquid Limit of Soils by the Three-Point Method
USBR 5360 Determining Plastic Limit and Plasticity Index of Soils

3.2 *ASTM Standards*:

E 11 Specification for Wire-Cloth Sieves for Testing Purposes
D 427 Shrinkage Factors of Soils

4. Summary of Method

4.1 The shrinkage limit of a soil is the maximum moisture content at which a reduction in moisture content will not cause a decrease in the volume of the mass of soil. The shrinkage ratio of a soil is the ratio of a given volume change, expressed as a percentage of the dry volume, to the corresponding change in moisture content above the shrinkage limit, expressed as a percentage of the mass of the ovendried soil. In this procedure the volume of an ovendried pat of soil is determined, by the displacement of water or mercury, to determine the shrinkage limit and the shrinkage ratio.

5. Significance and Use

5.1 The shrinkage factors covered by this procedure can only be determined on predominantly fine-grained cohesive soils which exhibit a dry strength when ovendried.

5.2 The term shrinkage limit, expressed as a moisture content in percent, represents the amount of water required to fill the voids of a given cohesive soil at its minimum void ratio obtained by ovendrying. The shrinkage limit can be used to evaluate the shrinkage potential, crack development potential, and swell potential of earthwork involving cohesive soils.

6. Terminology

6.1 Definitions are in accordance with USBR 3900. Terms of particular significance are:

6.1.1 *Shrinkage Limit.*–The maximum moisture content at which a reduction in moisture content will not cause a decrease in the volume of the soil mass (ASTM definition).

6.1.2 *Shrinkage Ratio.*–The ratio of (1) a given volume change, expressed as a percentage of the dry volume, to (2) the corresponding change in moisture content above the shrinkage limit, expressed as a percentage of the mass of the ovendried soil (ASTM).

6.1.3 *Volumetric Shrinkage.*–The decrease in volume, expressed as a percentage of the soil mass when dried, of a soil mass when the moisture content is reduced from a given percentage to the shrinkage limit (ASTM).

6.1.4 *Linear Shrinkage.*–Decrease in one dimension of a soil mass, expressed as a percentage of the original dimension, when the moisture content is reduced from a given value to the shrinkage limit (ASTM).

7. Apparatus

7.1 *General Apparatus*:

7.1.1 *Mortar* (5-1/2-inch-diameter); pestle, rubber tipped.

7.1.2 *Drying Oven.*–An oven, thermostatically controlled, preferably of the forced-draft type, and capable of maintaining a uniform temperature of 230±9 °F (110±5 °C) throughout the drying chamber.

7.1.3 *Balance or Scale.*–A typical balance or scale used for this designation must be readable to 0.01 g and have a capacity of about 500 g.

7.1.4 *Straightedge.*–A stiff metal straightedge of any convenient length. The scraping edge must have a straightness tolerance of ±0.005 inch (±0.13 mm) and must be beveled if it is thicker than 1/8 inch (3 mm).

7.1.5 *Sieve.*–U.S.A. Standard series No. 40 (425 μm) sieve, conforming to requirements of ASTM E 11.

7.1.6 *Evaporating Dish.*–An evaporating dish about 5-1/2 inches (140 mm) in diameter.

7.1.7 *Spatula or Pill Knife.*–A blade about 3 inches long and 3/4 inch wide (75 by 20 mm).

7.1.8 *Shrinkage Dish.*–A circular porcelain or Monel metal milk dish having a flat bottom and being about 1-3/4 inches in diameter and 1/2 inch high (45 by 15 mm).

7.2 *Equipment Unique to This Procedure*:

7.2.1 *Glass or Plastic Dish.*–Approximately 2-1/4 inches in diameter and 1-1/4 inches high (60 by 30 mm), the top rim of which is ground smooth and is in a plane essentially parallel with the bottom of the cup.

7.2.2 *Glass or Plastic Plate.*–With three metal prongs for immersing the soil pat in mercury as shown on figure 1.

7.2.3 *Graduated Cylinder.*–25-mL capacity, graduated to 0.1 mL.

7.2.4 *Mercury.*–Sufficient to fill the glass or plastic dish to overflowing.

7.2.5 *Water.*–Distilled.

7.2.6 *Sewing Thread.*–Fine.

7.2.7 *Microcrystalline Wax.*–Sufficient quantity to cover the soil pat.

7.2.8 *Wax Warmer.*–Sufficient temperature control to avoid overheating.

7.2.9 *Water bath.*–Of sufficient size to allow the soil pat to be submerged when determining mass in water.

7.2.10 *Siphon Can or Jar.*–Of appropriate size to allow submersion of soil pat (fig. 1).

8. Reagents and Materials

8.1 Distilled water is to be used for wetting the soil.

8.2 Mercury of sufficient quality and that foreign matter is not apparent.

9. Precautions

9.1 *Safety Precautions*:

9.1.1 This designation involves hazardous materials, operations, and equipment.

9.1.2 Mercury has been identified as a hazardous material; extreme care should be taken when working with it. Mercury should not be used without proper ventilation or if the user has open sores.

9.1.3 Wax melting equipment or hot wax may burn unprotected skin; overheated wax may burst into flames; therefore, extreme care should be taken when working with hot wax.

9.2 *Technical Precautions.*–The calibration of the shrinkage dish must be performed using the same method as is used to determine the volume of the soil pat. Method A utilizes an accurate mass measurement of water to determine the volume of the dish and soil pat. Method B utilizes a relative volume method to determine the volume of the dish and soil pat. Test errors will result if the volume measurement methods are interchanged.

10. Sampling, Test Specimens, and Test Units

10.1 *Sample Preparation.*–Prepare a representative soil sample in accordance with USBR 5205.

10.2 *Specimen Preparation*:

10.2.1 Pass approximately 30 grams of the air-dried soil through a No. 40 (425 μm) sieve and mix thoroughly.

10.2.2 Place the specimen in the evaporating dish or similar container and thoroughly mix the specimen with distilled water. Add a sufficient amount of water to fill the soil voids and make the soil pastey enough to be readily worked into the shrinkage dish without inclusion of air bubbles. The amount of water required to furnish friable soils with the desired consistency is equal to or slightly greater than the liquid limit. The amount of water necessary to furnish plastic soils with the desired consistency may exceed the liquid limit by as much as 10 percent. It has been found that an acceptable moisture content is one that will produce about a 1/2-inch (13-mm) closure of the liquid limit groove in 10 blows.

11. Calibration and Standardization

11.1 Verify that equipment is currently calibrated in accordance with the applicable calibration procedure. If the calibration is not current, perform the calibration before using the equipment for this procedure.

USBR 1012 Calibrating Balances and Scales
USBR 1020 Calibrating Ovens
USBR 1025 Calibrating Sieves and Screens

11.2 *Shrinkage Dish-Volume Calibration—Method A*:

11.2.1 All data are to be recorded on the "Shrinkage Dish-Volume Calibration" form as shown on figure 2.

11.2.2 Lightly grease the inside of the shrinkage dish and face of the glass plate.

NOTE 1.–The face of the glass plate is greased to provide an adequate water tight seal while moving the dish and glass plate to the scale.

11.2.3 Determine and record the mass of the greased dish and greased plate.

11.2.4 Place water into the greased dish to overflowing.

11.2.5 Remove the excess water by pressing the greased glass plate over the top of the dish. Be sure all of the air is removed from within the dish.

11.2.6 Determine and record the mass of the greased dish, greased plate, and water.

11.2.7 Calculate and record the value of the mass of water.

11.2.8 Determine and record water temperature.

11.2.9 Obtain and record the absolute density of water from table 1 for the temperature recorded in subparagraph 11.2.8.

11.2.10 Calculate and record the volume of the shrinkage dish.

11.2.11 Completely clean the dish and the glass plate and repeat subparagraphs 11.2.2 through 11.2.10.

11.2.12 If the difference in volume between the two trials is greater than ± 0.01 cm^3, repeat the procedure until the difference between any two trials is less than ± 0.01 cm^3. Average and record the results from the two trials.

11.3 *Shrinkage Dish-Volume Calibration—Method B*:

11.3.1 The shrinkage dish volume is to be recorded on the "Shrinkage Limit and Shrinkage Ratio" form as shown on figure 3.

11.3.2 Lightly grease the inside of the shrinkage dish and face of the glass plate.

11.3.3 Determine and record the mass of the greased dish and plate.

11.3.4 Fill the shrinkage dish with mercury until it just begins to overflow (see subpar. 9.1 on handling the mercury).

11.3.5 Remove the excess mercury by pressing a glass plate firmly over the top of the dish.

11.3.6 Measure, by means of a glass graduated cylinder, the volume of mercury held in the dish. Record this volume as the volume of the shrinkage dish, *V*, on figure 3.

12. Conditioning

12.1 Place the material for each soil specimen, as prepared in subparagraph 10.2, in a moistureproof container and store for a minimum standing time of 16 hours.

13. Procedure

13.1 All data are to be recorded on the "Shrinkage Limit and Shrinkage Ratio" form as shown on figure 3.

13.2 Lightly grease the inside of the shrinkage dish.

13.3 Determine the mass of the greased shrinkage dish and record the value as the mass of the empty shrinkage dish.

13.4 Place, in the center of the dish, an amount of the wetted soil equal to about one-third the volume of the dish and cause the soil to flow to the edges by tapping the dish on a firm surface cushioned by several layers of blotting paper or similar material. Add an amount of soil approximately equal to the first portion, and tap the dish until the soil is thoroughly compacted and all included air has been brought to the surface. Add more soil and continue the tapping until the dish is completely filled and excess soil stands out about its edge. Strike off the excess soil with a straightedge, and wipe off all soil adhering to the outside of the dish.

13.5 Determine the mass of the dish immediately after it is filled and record the struck measure value as the mass of dish plus wet soil.

13.6 Allow the soil pat to dry in air until the color of the pat turns from dark to light. Ovendry the pat to constant mass at 230 ± 9 °F (110 ± 5 °C), and record the mass of dish plus dry soil.

NOTE 2: Drying the soil pat in air may produce cracking of the soil due to rapid moisture losses in dry climates. If this problem is encountered, it may be necessary to dry the soil in a humidity controlled environment.

13.7 *Method A* (wax method).–Determine the volume of the dried soil pat:

13.7.1 Make a "cradle" for the soil pat by tying together the loose ends of a 250- to 300-mm piece of sewing thread (fig. 4).

13.7.2 Place the soil pat on the loop of thread (fig. 5).

13.7.3 Bring the tied end of thread over the soil pat and through the looped end of the thread (fig. 6).

13.7.4 Tighten by pulling the tied end through the loop (fig. 7).

13.7.5 Immerse the dry pat of soil in melted wax, holding the dry pat with the sewing thread, completely coating the pat. Do not allow air bubbles to develop in the wax coating. If air bubbles are present, use a sharp object to cut out the bubble; refill the hole with wax.

CAUTION: The melted wax and associated equipment is hot and care should be exercised to avoid burns.

13.7.6 Remove the pat of soil from the melted wax and allow the wax coating to cool.

13.7.7 Determine the mass of the wax-coated pat of soil in air and record the value as the mass in air of the dry soil and wax.

13.7.8 Determine the mass of the wax-coated pat of soil as it is suspended from a balance while submerged in a water bath. Record this as the mass in water of the dry soil and wax.

13.7.9 Complete the calculations as required on the form as shown in figure 3.

13.8 *Method A* (wax method).–Alternate method to determine the volume of the dried soil pat:

13.8.1 Perform subparagraphs 13.7.1 through 13.7.6 to prepare the dried soil pat for this method.

13.8.2 Fill the siphon can to the top with water, with the siphon tube closed.

13.8.3 Open the siphon tube and allow the water to drain from the siphon until the water level has stabilized.

13.8.4 Place the graduated cylinder below the siphon tube.

13.8.5 Close the siphon tube to prevent water flow while submerging the wax-coated soil pat in the water.

13.8.6 Submerge the wax-coated soil pat into the water and allow the water surface to stabilize.

13.8.7 Open the siphon tube and allow the water to drain into the graduated cylinder. Avoid any water loss while draining.

13.8.8 Record the volume of the water in the graduated cylinder as volume of dry soil and wax.

13.8.9 Complete the calculations as required on the data form as shown on figure 3.

13.9 *Method B* (mercury method).–Determine the volume of the dry soil pat:

13.9.1 Place the glass or plastic dish in an evaporating dish as shown on figure 1. Fill the glass dish to overflow with mercury.

13.9.2 Remove the excess mercury by pressing the glass plate with the three prongs (fig. 1) firmly over the top of the dish. The excess mercury will collect in the evaporating dish.

13.9.3 Carefully wipe off any mercury that may be adhering to the outside of the dish.

13.9.4 Place the glass or plastic dish, filled with mercury, in the evaporating dish and place the soil pat on the surface of the mercury.

13.9.5 Carefully force the pat under the mercury with the glass plate, with the three prongs (fig. 1), and press the plate firmly over the top of the cup. It is essential that no air be trapped under the soil pat.

13.9.6 Using a graduated cylinder, measure the volume of mercury displaced into the evaporating dish. Record the value as the volume of dry soil, V_o (see fig. 3).

13.9.7 Complete the calculations as required on the data form as shown on figure 3.

14. Calculations

14.1 *Calculation of Moisture Content*:

14.1.1 Calculate the moisture content of the soil at the time it was placed in the dish expressed as a percentage of the dry mass of the soil as follows:

$$w = 100\left(\frac{m - m_o}{m_o}\right) \quad (1)$$

where:

w = moisture content of the soil when placed in the dish, %
m = mass of wet soil obtained by subtracting the mass of the shrinkage dish from the mass of the dish and wet soil, g
m_o = mass of dry soil obtained by subtracting the mass of the shrinkage dish from the mass of the dish and dry pat, g
100 = convert from decimal to percent

14.2 *Calculations for Method A*:

14.2.1 Determine the volume of the shrinkage dish as follows:

$$V = \frac{m}{\gamma_w} = \frac{\text{mass of water, g}}{\text{absolute density of water, g/cm}^3} \quad (2)$$

Record this as the volume of the shrinkage dish, V.

14.2.2 Determine the volume of dry pat of soil:

$$\text{Mass of water} = (\text{mass of dish + wet soil}) - (\text{mass of dish + dry soil}) \quad (3)$$

$$\text{Mass of dry soil, } m_o = (\text{mass of dish + dry soil}) - (\text{mass of dish}) \quad (4)$$

$$\text{Moisture content, } w = 100\left(\frac{\text{mass of water}}{m_o}\right) \quad (5)$$

Mass of wax = (mass in air of dry soil + wax) - (mass in air of dry soil) (6)

Volume of pat + wax = (mass in air of dry soil+wax) - (mass in water of dry soil+wax) (7)

$$\text{Volume of wax} = \frac{\text{mass of wax, g}}{\text{(specific gravity of wax)1 g/cm}^3} \quad (8)$$

Volume of dry soil, V_o = (volume of pat + wax) - (volume of wax) (9)

NOTE 3. - Absolute density of water is assumed equal to 1.0; if more accuracy is required, corrections for temperature may be necessary.

14.2.3 Shrinkage limit *SL*:

$$SL = w - 100\left(\frac{V - V_o}{m_o}\right)\rho_w \quad (10)$$

where:

- SL = shrinkage limit
- w = moisture content of wet soil, in percentage of the mass of ovendried soil, %
- V = volume of wet soil pat = volume of the shrinkage dish
- V_o = volume of dry soil pat
- m_o = mass of ovendried soil pat, g
- ρ_w = 1 g/cm³ at 4 °C

14.2.4 Shrinkage ratio, *R*:

$$R = \frac{m_o}{V_o} \quad (11)$$

14.3 *Calculations for Method B*:

14.3.1 Calculate the shrinkage limit, *SL*, from the data obtained in the volumetric shrinkage determination as follows:

$$SL = w - 100\left(\frac{V - V_o}{m_o}\right)\rho_w \quad (12)$$

where:

- SL = shrinkage limit
- w = moisture content of wet soil, in percentage of the mass of ovendried soil, %
- V = volume of wet soil pat = volume of the shrinkage dish
- V_o = volume of dry soil pat
- m_o = mass of ovendried soil pat, g
- ρ_w = 1 g/cm³ at 4 °C

14.3.1.1 *Optional Method*.-When both the specific gravity, G_s, and the shrinkage ratio, *R*, are known, calculate the shrinkage limit as follows:

$$SL = 100\left(\frac{1}{R} - \frac{1}{G_s}\right) \quad (13)$$

14.3.2 Calculate the shrinkage ratio, *R*, from the data obtained in the volumetric shrinkage determination by the following equation:

$$R = \frac{m_o}{V_o} \quad (14)$$

where m_o and V_o are given above.

14.4 *Calculation of Volumetric Shrinkage, Linear Shrinkage, and Specific Gravity*:

14.4.1 The volumetric shrinkage, V_s, is calculated using the following equation:

$$V_s = R(w_1 - SL) \quad (15)$$

where:

- V_s = volumetric shrinkage
- w_1 = given percentage of moisture content, %
- SL = shrinkage limit
- R = shrinkage ratio

14.4.2 The linear shrinkage, L_s, is calculated by the following equation:

$$L_s = 100 \; 1 - \left(\frac{100}{V_s + 100}\right)^{1/3} \quad (16)$$

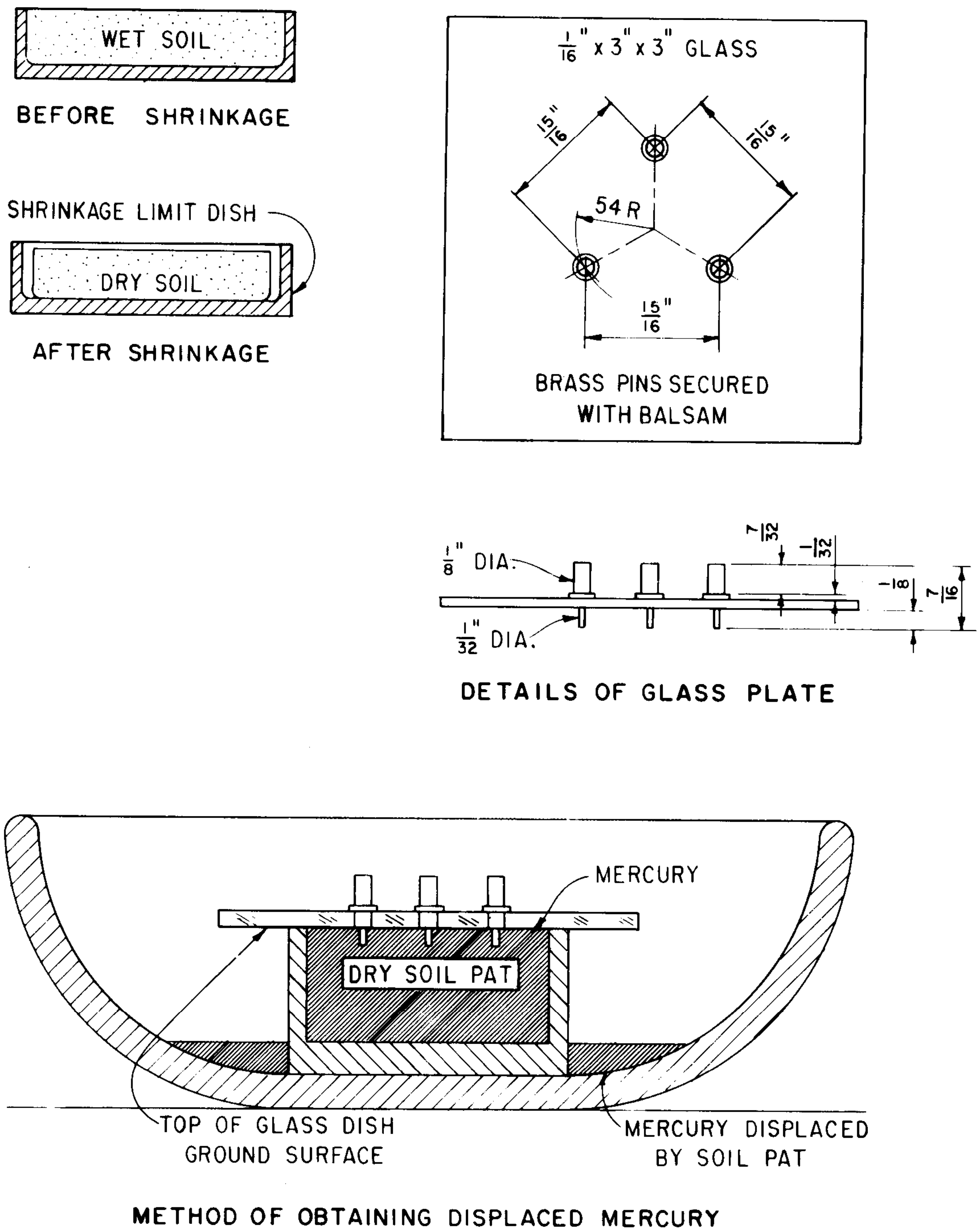
14.4.3 The specific gravity of the soil solids, G_s, may be calculated by the following equation:

$$G_s = \frac{1}{\frac{1}{R} - \frac{SL}{100}} \quad (17)$$

15. Report

15.1 The report is to consist of a completed and checked "Shrinkage Limit and Shrinkage Ratio" form (fig. 3).

15.2 All calculations are to show a checkmark.



METRIC EQUIVALENTS

in.	1/32	1/16	1/8	7/32	7/16	15/16	3
mm	0.8	1.6	3.2	5.6	11.1	23.8	76.2

Figure 1. - Apparatus for determining the volumetric change from ASTM D 427, vol. 04.08.

7-2312 (9-85) Bureau of Reclamation	SHRINKAGE DISH-VOLUME CALIBRATION	Designation USBR 5365

Dish No. ________________

Calibration performed by ______________________________ Date ______________________

Calibration checked by ______________________________ Date ______________________

Trial A

1. Mass of greased dish + greased plate + water . . . . ____________ g
2. Mass of greased dish + greased plate . . . . ____________ g
3. Mass of water = (1) – (2) . . . . ____________ g
4. Temperature of water. . . . . ____________ °C
5. Absolute density of water from table 1 . . . . ____________
6. Volume of dish = $\frac{(3)}{(5)}$ . . . . ____________ cm^3

Trial B

7. Mass of greased dish + greased plate + water . . . . ____________ g
8. Mass of greased dish + greased plate . . . . ____________ g
9. Mass of water = (7) – (8) . . . . ____________ g
10. Temperature of water. . . . . ____________ °C
11. Absolute density of water from table 1 . . . . ____________
12. Volume of dish = $\frac{(9)}{(11)}$ . . . . ____________ cm^3
13. Difference between Trial A and Trial B = (6) – (12) . . . . ____________ cm
14. Average dish volume = $\frac{(6) + (12)}{2}$ . . . . ____________ cm^3

NOTE: The difference in volume between trials is to be equal to or less than $\pm$ 0.01 cm^3.

Figure 2. – Shrinkage dish–volume calibration sheet – method A.

7-2311 (9-65) Bureau of Reclamation	SHRINKAGE LIMIT AND SHRINKAGE RATIO				Designation USBR 5365 - __ __
SAMPLE NO.		FEATURE		PROJECT	
TESTED BY	DATE	COMPUTED BY	DATE	CHECKED BY	DATE

Method A (Wax Method)

1. Shrinkage dish No. ____________
2. Mass of dish + wet soil .... ____________ g
3. Mass of dish + dry soil .... ____________ g
4. Mass of dish .... ____________ g
5. Mass of water = (2 – 3) .... ____________ g
6. Mass of dry soil (M_O) = (3 – 4) .... ____________ g
7. Moisture content (w) = (5)/(6) x 100 .... ____________ %
8. Mass in air of dry soil + Wax* .... ____________ g
9. Mass of wax = (8 – 6) .... ____________ g
10. Mass in water of soil + wax .... ____________ g
11. Volume of soil + wax = (8 – 10) .... ____________ cm^3
12. Specific gravity of wax** .... ____________
13. Volume of wax = (9/12) .... ____________ cm^3
14. Volume of dry soil (V_O) = (11 – 13) .... ____________ cm^3
15. Volume of dish (V) (From calibration sheet) .... ____________ cm^3
16. ($V - V_O$) = (15 – 14) .... ____________ cm^3
17. $\frac{V - V_O}{M_O} \times 100 = \frac{(16)}{(6)} \times 100$ .... ____________ cm^3/g
18. Shrinkage limit (SL) = (7 – 17) .... ____________ %
19. Shrinkage ratio (R) = (6/14) .... ____________ g/cm^3

---

* The term wax denotes microcrystalline wax.

** Specific Gravity of wax is obtained from manufacturer (usually 0.91)

Sample No.

Method B (Mercury Method)

1. Shrinkage dish No. ____________
2. Mass of dish + wet soil .... ____________ g
3. Mass of dish + dry soil .... ____________ g
4. Mass of dish .... ____________ g
5. Mass of water = (2 – 3) .... ____________ g
6. Mass of dry soil (M_O) = (3 – 4) .... ____________ g
7. Moisture content (w) = (5)/(6) x 100 .... ____________ %
8. Volume of dish (V) (From calibration sheet) .... ____________ cm^3
9. Volume of dry soil (V_O) .... ____________ %
10. $V - V_O$ = (8 – 9) .... ____________ cm^3
11. $\frac{V - V_O}{M_O} \times 100 = \frac{(10)}{(6)} \times 100$ .... ____________ cm^3/g
12. Shrinkage limit (SL) = (7 – 11) .... ____________ %
13. Shrinkage ratio (R) = (6/9) .... ____________ g/cm^3

GPO 848-601

Figure 3. – Shrinkage limit and shrinkage ratio sheet.

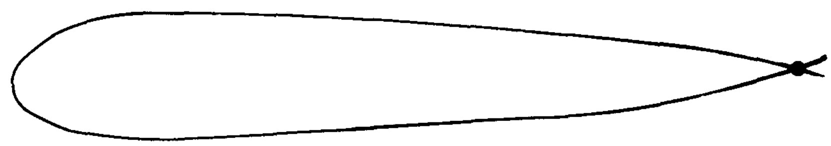


Figure 4. – "Cradle" for dry soil pat.

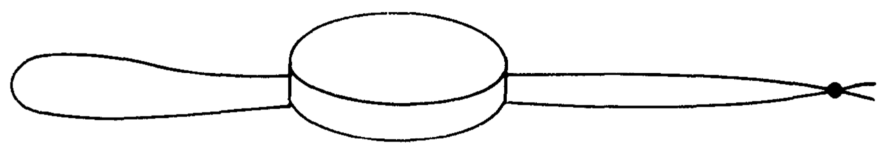


Figure 5. – Pat on loop of thread.

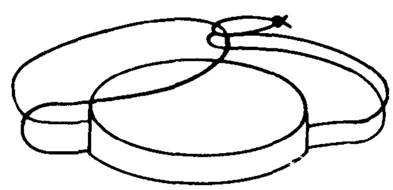


Figure 6. – Tied end over dry soil pat and through looped end.

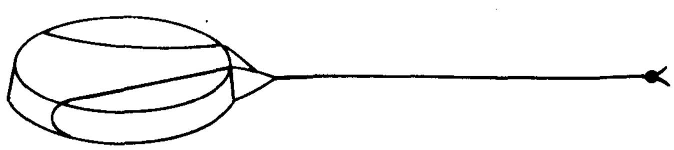


Figure 7. – Tighten by pulling tied end to position shown.

Table 1. – Absolute density of water in grams per cubic centimeter.†

Degrees C	0	1	2	3	4	5	6	7	8	9
0	0.999841	847	854	860	866	872	878	884	889	895
1	900	905	909	914	918	923	927	930	934	938
2	941	944	947	950	953	955	958	960	962	964
3	965	967	968	969	970	971	972	972	973	973
4	973	973	973	972	972	972	970	969	968	966
5	965	963	961	959	957	955	952	950	947	944
6	941	938	935	931	927	924	920	916	911	907
7	902	898	893	888	883	877	872	866	861	855
8	849	843	837	830	824	817	810	803	796	789
9	781	774	766	758	751	742	734	726	717	709
10	700	691	682	673	664	654	645	635	625	615
11	605	595	585	574	564	553	542	531	520	509
12	498	486	475	463	451	439	427	415	402	390
13	377	364	352	339	326	312	299	285	272	258
14	244	230	216	202	188	173	159	144	129	114
15	099	084	069	054	038	023	007	*991	*975	*959
16	0.998943	926	910	893	877	860	843	826	809	792
17	774	757	739	722	704	686	668	650	632	613
18	595	576	558	539	520	501	482	463	444	424
19	405	385	365	345	325	305	285	265	244	224
20	203	183	162	141	120	099	078	056	035	013
21	0.997992	970	948	926	904	882	860	837	815	792
22	770	747	724	701	678	655	632	608	585	561
23	538	514	490	466	442	418	394	369	345	320
24	296	271	246	221	196	171	146	120	095	069
25	044	018	*992	*967	*941	*914	*888	*862	*836	*809
26	0.996783	756	729	703	676	649	621	594	567	540
27	512	485	457	429	401	373	345	317	289	261
28	232	204	175	147	118	089	060	031	002	*973
29	0.995944	914	885	855	826	796	766	736	706	676
30	646	616	586	555	525	494	464	433	402	371

† For inch-pound applications, multiply the values in this table by 62.4280 to convert to lbm/ft^3.
* First three significant figures shown in line below.

APPENDIX B

CALIBRATION OF SHRINKAGE LIMIT DISH VOLUME

INTRODUCTION

The volume of shrinkage limit dishes has been determined by measuring, with a graduated cylinder, the volume of mercury that the dish holds [6]. This method was used because the same type of measurement was made to determine the volume of the soil pat. With the elimination of mercury in the procedure for determining the volume of the soil pat, the method used for measuring the volume of the dishes needed review.

Determining the dish volume with water provides the required accuracy to perform accurate shrinkage limit testing by the alternate wax method. The water method eliminates mercury from the calibration procedure.

DISCUSSION

The shrinkage dishes in the Geotechnical Branch laboratory were calibrated with both water and mercury using this procedure. The volume determinations are summarized in tables B-1 and B-2 and on figures B-1, B-2, and B-3.

There was acceptable correlation between dish volumes determined by mercury and water. There was also acceptable dish volume repeatability when calibration was performed by independent operators. The volume difference is cm^3 versus the frequency of difference as shown on figure B-1. The mean dish volume difference obtained by using mercury and water was 0.03 cm^3 and 0.035 cm^3 between dish volumes obtained by water determinations by independent operators. These differences are acceptable as the maximum difference of 0.15 cm^3 changes the shrinkage limit value by 1 percentage point. Since the shrinkage limit is used as a general indicator of soil expansion characteristics, 1 percentage point is not considered significant. However, it is recommended that several practice calibration trials be performed prior to actual dish calibration to familiarize the person with the procedure.

The repeatability shown on figures B-2 and B-3 indicates an acceptable correlation. Two studies were performed: (1) to compare the water and mercury method, with results shown on figure 9, and (2) to compare repeatability of the water method with results shown on figure B-3.

CONCLUSIONS

The use of water to calibrate shrinkage dish volumes provides acceptably accurate values.

PROCEDURE

1. Purpose. – Porcelain or stainless steel shrinkage dishes are used in determining the shrinkage limit of soils. The saturated soil pat is prepared in the shrinkage dish, so the volume of the soil pat is equal to the volume of the dish. Thus, it is necessary to accurately determine the volume of the shrinkage dish.

2. Apparatus:

   a. Glass or clear plastic plate, approximately 3¼- by 3¼-inches; ⅛ to ¼ inch thick

   b. Balance, 100-gram capacity, graduated to 0.01 gram

   c. Celsius thermometer, 0.2 °C graduations (thermometers graduated to 0.5 °C may be used if thermometers graduated to 0.2 °C are not available)

   d. Distilled water

   e. Towel or other appropriate absorbent wipe

   f. Petroleum base lubricant

3. Calibration:

   a. Lightly grease one side of the plate and the inside of the shrinkage dish with a petroleum base lubricant. (The grease is used to form a watertight seal around the edge of the dish.) Obtain the weight of the dish and the greased glass plate to the nearest 0.01 gram.

   b. The dish and water should be near normal room temperature (18 to 24 °C). Fill the shrinkage dish slightly above its rim with water. Slide the plate, with greased side toward the dish (the grease will assist in providing a watertight seal), over the top of the dish so that it remains completely filled with water and no air bubbles are entrapped. With a clean dry towel, dry the excess water from the outside of the dish and plate. Record the weight of the covered dish filled with water.

   c. The difference between the weights in 3.a. and 3.b. yields the weight of water necessary to fill the dish. Determine the temperature of the water and find the absolute density of water at this temperature (table 10-1, designation E-10 of the [Bureau's] *Earth Manual*).

   d. The volume of the dish is obtained by dividing the weight of water in the dish by its absolute density. Calculate the volume to the nearest 0.01 cm^3.

e. Two volume determinations should be performed on each dish. The volumes should agree to within ± 0.03 cm^3. The average of the two volume determinations should be used as the volume of the shrinkage dish. All of the above measurements should be verified and calculations checked by a second person. An example data form is shown in appendix A on figure 2.

Table B-1. – Shrinkage dish volume cm^3 – dish-type porcelain.

Dish No.	Volume by mercury	Volume by water A	Volume by water B	Mercury-water volume differences	Water A-B volume differences
101	14.34	14.31	14.35	0.03	0.04
102	14.21	14.25	14.26	.04	.01
103	14.66	14.66	14.62	.00	.04
104	14.01	13.99	14.04	.02	.05
105	14.40	14.39	14.38	.01	.01
106	14.49	14.48	14.54	.01	.06
107	14.34	14.33	14.24	.01	.11
108	14.29	14.26	14.26	.03	.00
109	14.54	14.51	14.54	.03	.03
110	14.43	14.43	—	.00	—
111	14.43	14.33	14.48	.10	.15
112	14.50	14.44	14.56	.06	.12
113	14.50	14.46	14.48	.04	.02
114	14.20	14.10	14.22	.10	.12
115	14.33	14.33	14.34	.00	.01

Table B-2. – Shrinkage dish volume cm^3 – dish-type stainless steel.

Dish No.	Volume by mercury	Volume by water	Volume difference
102	13.31	13.27	0.04
103	13.30	13.20	.10
105	13.30	13.26	.04
106	13.32	13.24	.06
108	13.20	13.13	.07
109	13.36	13.34	.02

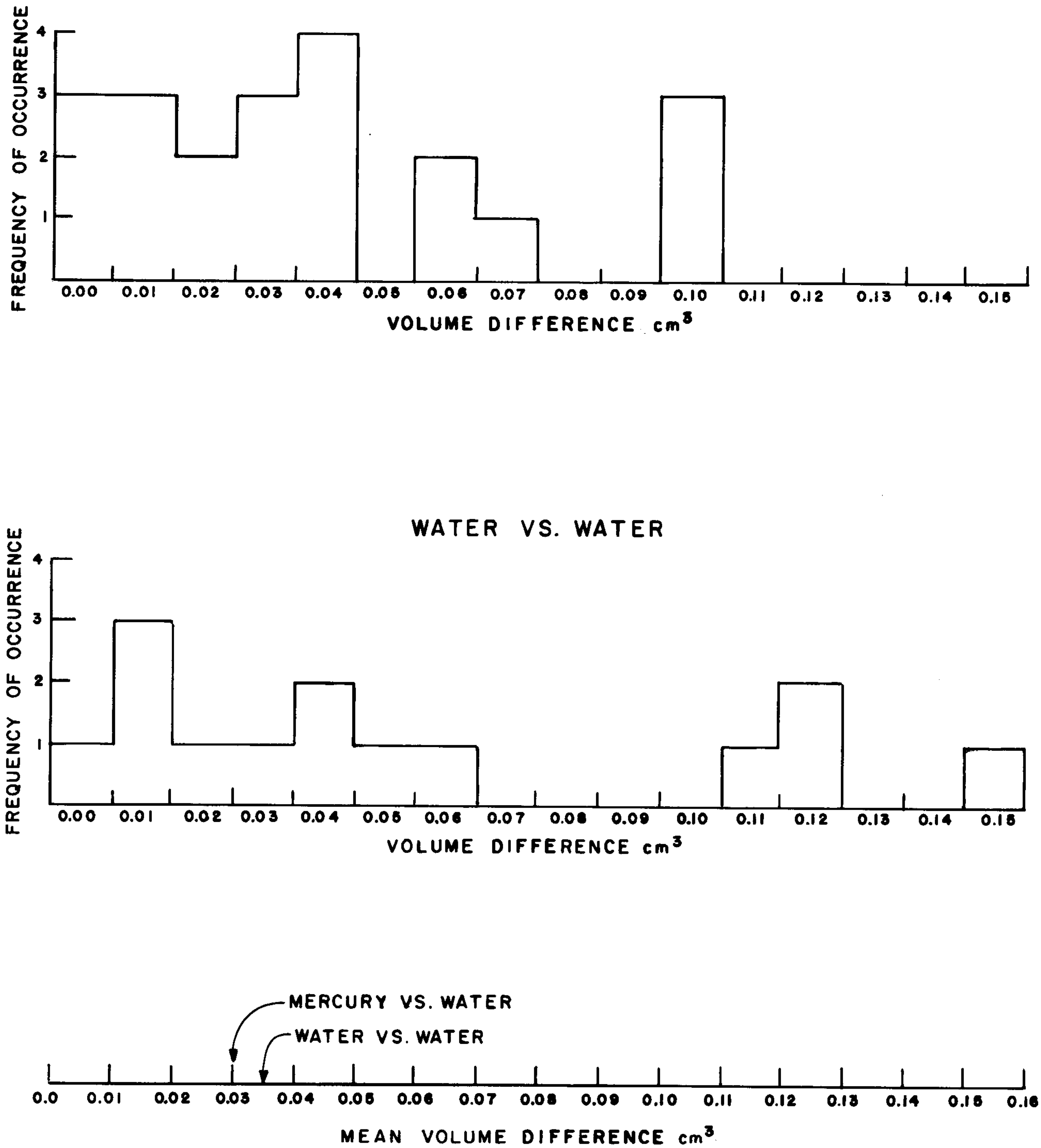


Figure B-1. – Frequency of occurrence versus volume difference.

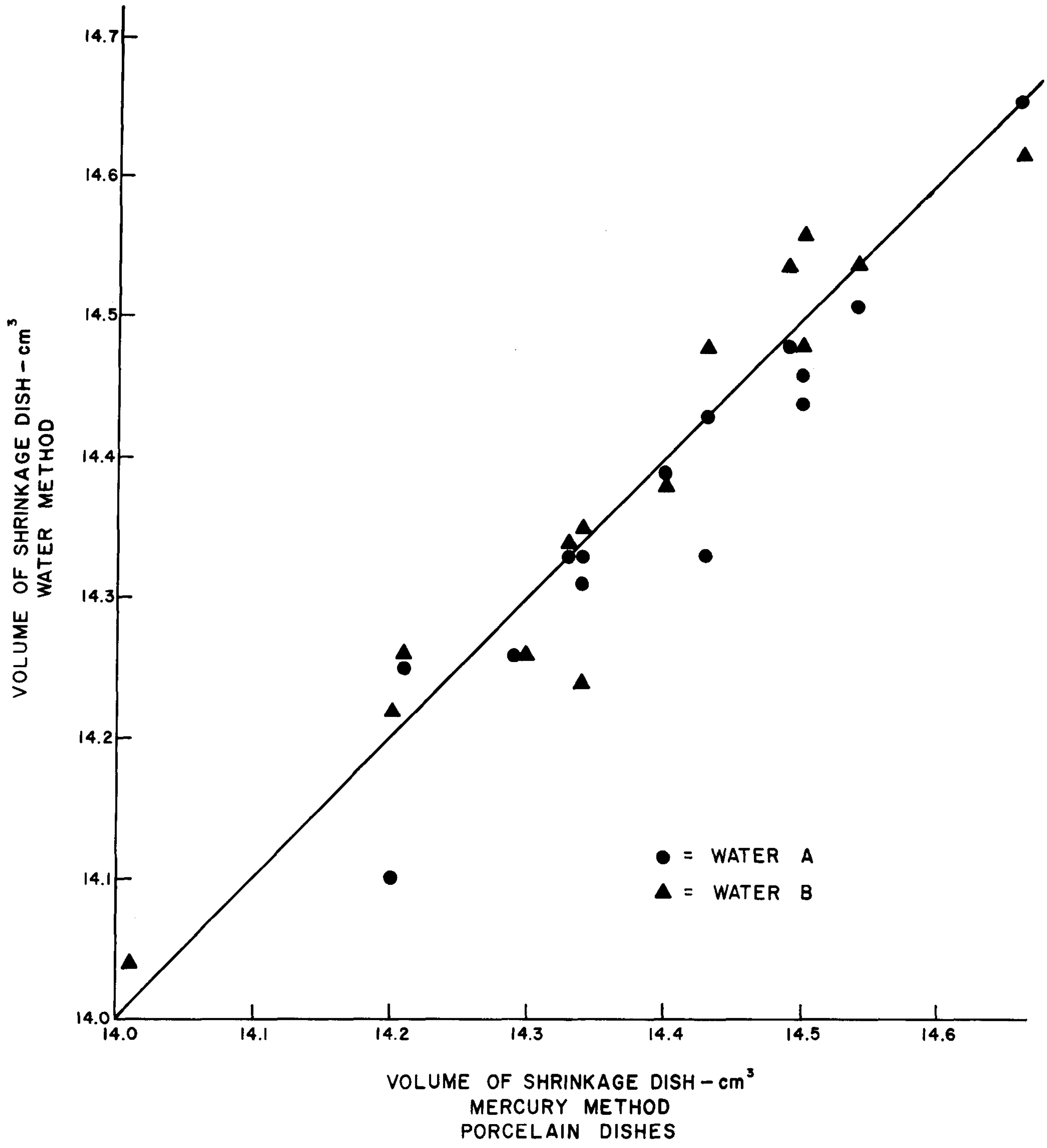


Figure B-2. – Volume of shrinkage dish – mercury versus water methods.

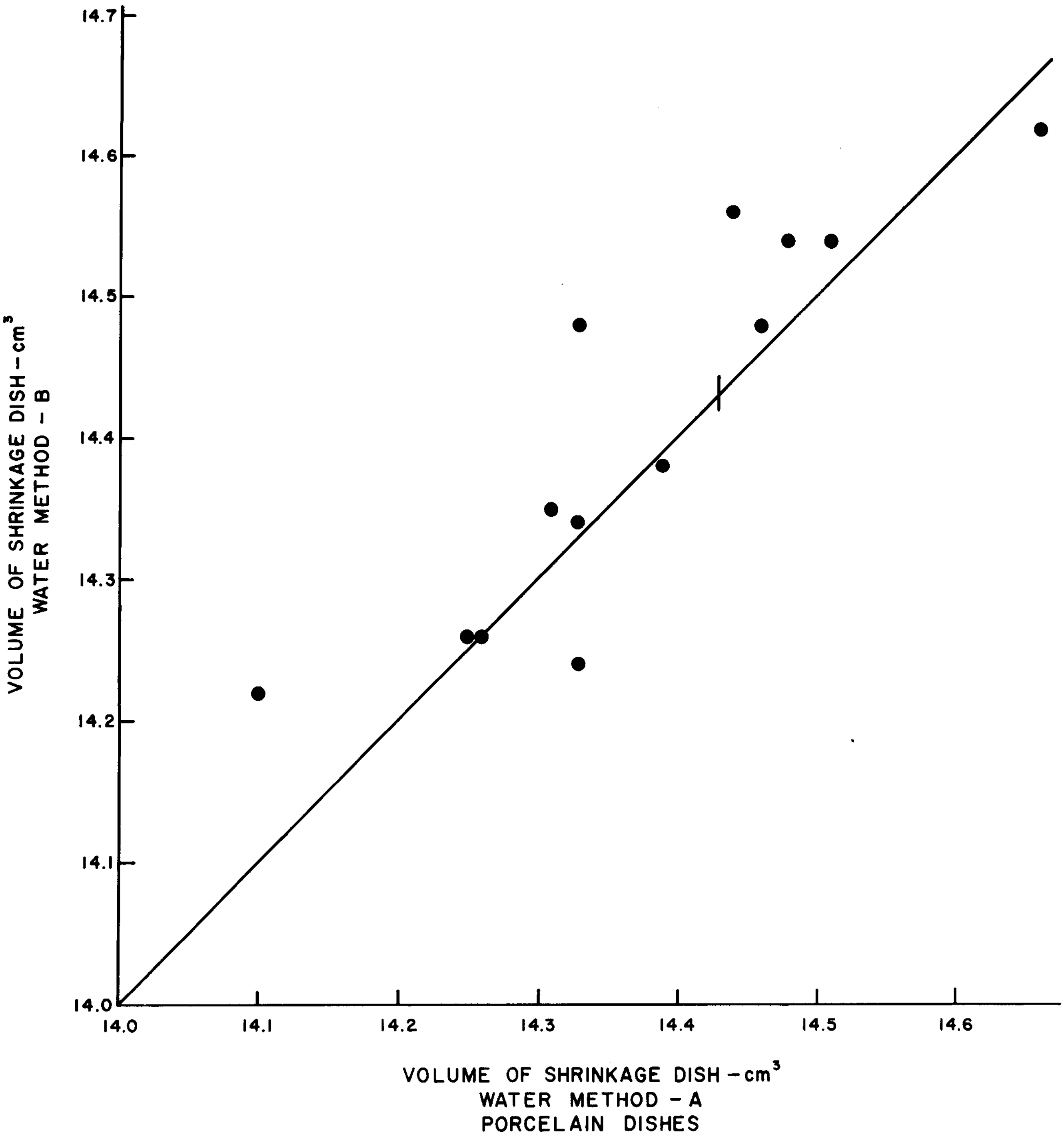


Figure B-3. – Volume of shrinkage dish – water method A versus water method B.

GPO 852-570

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.